

WHAT IS CLAIMED IS:

1 1. A composition comprising:

2 an inorganic particle,

3 a linking group which has a distal end and a proximal end, the distal end being bound
4 to an outer surface of the inorganic particle and the proximal end including a first charged or
5 ionizable moiety, and

6 a macromolecule having a second charged or ionizable moiety, wherein the first and
7 second charged or ionizable moieties electrostatically associate the inorganic particle with the
8 macromolecule to form an ionic conjugate.

1 2. The composition of claim 1, wherein the inorganic particle is a

2 semiconducting nanocrystal.

1 3. The composition of claim 2, wherein the semiconductor nanocrystal includes
2 a first semiconductor material selected from the group consisting of a Group II-VI
3 compound, a Group II-V compound, a Group III-VI compound, a Group III-V compound, a
4 Group IV-VI compound, a Group I-III-VI compound, a Group II-IV-VI compound, and a
5 Group II-IV-V compound.

1 4. The composition of claim 3, wherein the first semiconductor material is
2 selected from the group consisting of ZnS, ZnSe, ZnTe, CdS, CdSe, CdTe, HgS, HgSe, HgTe,
3 AlN, AlP, AlAs, AlSb, GaN, GaP, GaAs, GaSb, GaSe, InN, InP, InAs, InSb, TlN, TlP, TlAs,
4 TlSb, PbS, PbSe, PbTe, and mixtures thereof.

1 5. The composition of claim 4, wherein the first semiconductor material is CdSe.

1 6. The composition of claim 5, wherein the first semiconductor material is
2 overcoated with a second semiconductor material.

1 7. The composition of claim 6, wherein the second semiconductor material is
2 ZnS, ZnO, ZnSe, ZnTe, CdS, CdO, CdSe, CdTe, MgS, MgSe, HgO, HgS, HgSe, HgTe, AlN,

3 AlP, AlAs, AlSb, GaN, GaP, GaAs, GaSb, GaSe, InN, InP, InAs, InSb, TiN, TiP, TiAs, TiSb,
4 PbS, PbSe, PbTe, SiO₂, or mixtures thereof.

1 8. The composition of claim 1, wherein the inorganic particle further comprises a
2 plurality of linking groups each independently including a third charged or ionizable moiety.

1 9. The composition of claim 8, further comprising a plurality of macromolecules,
2 each of the macromolecules including a fourth charged or ionizable moiety, wherein the
3 plurality of macromolecules are associated with the inorganic particle via electrostatic
4 interaction with the plurality of inorganic particle linking groups.

1 10. The composition of claim 1, wherein the inorganic particle comprises Ag, Au,
2 or a phosphor.

1 11. The composition of claim 1, wherein the first charged or ionizable group
2 includes an hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or
3 quaternary ammonium.

1 12. The composition of claim 1, wherein the second charged or ionizable group
2 includes an hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or
3 quaternary ammonium.

1 13. The composition of claim 1, wherein the linking group has the formula:

$$(R_1)_a - R_2 - [(R_3)_b (R_4)_c]_d$$

2 wherein

3 R₁ is selected from the group consisting of C1-C100 heteroalkyl, C2-C100
4 heteroalkenyl, heteroalkynyl, -OR, -SH, -NHR, -NR'R'', -N(O)HR, -N(O)R'R'', -PHR,
5 -PR'R'', -P(NR'R'')NR'R'', -P(O)R'R'', -P(O)(NR'R'')NR'R'', -P(O)(OR')OR'', -P(O)OR,
6 -P(O)NR'R'', -P(S)(OR')OR'', and -P(S)OR, wherein R, R', R'' are independently selected
7 from the group consisting of H, a branched or unbranched C1-C100 alkyl, a branched or
8 unbranched C2-C100 alkenyl, a branched or unbranched C2-C100 alkynyl, a branched or
9 unbranched C1-C100 heteroalkyl, a branched or unbranched C2-C100 heteroalkenyl, a

11 branched or unbranched C₂-C₁₀₀ heteroalkynyl, with the proviso that when a is greater than
12 1 the R₁ groups can be attached to the R₂ or R₃ groups at the same or different atoms within
13 those groups, the R₁ groups can be the same or different, or the R₁ groups can form a six,
14 seven, eight, nine, or ten membered cycloalkyl, cycloalkenyl, thereocyclic, aryl, heteroaryl,
15 or a six- to thirty-membered crown ether or heterocrown ether;

16 R₂ is selected from a bond, a branched or unbranched C₂-C₁₀₀ alkylene, a branched
17 or unbranched C₂-C₁₀₀ alkenylene, a branched or unbranched C₂-C₁₀₀ heteroalkenylene,
18 cycloalkyl, cycloalkenyl, cycloalkynyl, heterocyclic, aryl, and heteroaryl;

19 R₃ is selected from a branched or unbranched C₂-C₁₀₀ alkylene, a branched or
20 unbranched C₂-C₁₀₀ alkenylene, a branched or unbranched C₂-C₁₀₀ heteroalkenylene,
21 cycloalkyl, cycloalkenyl, cycloalkynyl, heterocyclic, aryl, and heteroaryl;

22 R₄ is selected from the group consisting of hydrogen, a carboxylate, a
23 thiocarboxylate, an amide, a hydrazine, a sulfonate, a sulfoxide, a sulfone, a sulfite, a
24 phosphate, a phosphonate, a phosphonium ion, an alcohol, a thiol, an amine, an ammonium,
25 an alkyl ammonium, a nitrate; and

26 a is 1 to 40, b is 0 to 3, c is 1 to 30, d is 1 to 3, and when d is 2 or 3 the R₃ groups can
27 be the same or different or can be linked together to form a five to ten members cycloalkyl,
28 cycloalkenyl, heterocyclic, aryl, or heteroaryl.

1 14. The composition of claim 1, wherein the linking group has the formula
2 HS-C₂H₄-CH(SH)-(C₄H₈)-COOH.

1 15. The composition of claim 1, wherein the macromolecule includes a
2 polypeptide or polynucleotide.

1 16. The composition of claim 15, wherein the macromolecule includes a
2 polypeptide.

1 17. The composition of claim 16, wherein the second charged or ionizable moiety
2 is a leucine zipper.

1 18. The composition of claim 16, wherein the second charged or ionizable moiety
2 is polyaspartate.

1 19. The composition of claim 16, wherein the polypeptide includes a maltose
2 binding protein.

1 20. The composition of claim 16, wherein the polypeptide includes an
2 immunoglobulin G binding protein.

1 21. A composition comprising:
2 an inorganic particle,
3 a linking group which has a distal end and a proximal end, the distal end being bound
4 to an outer surface of the inorganic particle and the proximal end including a first charged or
5 ionizable moiety, and
6 a fusion protein including a second charged or ionizable moiety, wherein the first and
7 second charged or ionizable moieties electrostatically associate the inorganic particle with the
8 fusion protein to form an ionic conjugate.

1 22. The composition of claim 21, wherein the inorganic particle is a
2 semiconducting nanocrystal.

1 23. The composition of claim 22, wherein the semiconductor nanocrystal includes
2 a first semiconductor material selected from the group consisting of a Group II-VI
3 compound, a Group II-V compound, a Group III-VI compound, a Group III-V compound, a
4 Group IV-VI compound, a Group I-III-VI compound, a Group II-IV-VI compound, and a
5 Group II-IV-V compound.

1 24. The composition of claim 21, wherein the inorganic particle further comprises
2 a plurality of linking groups each independently including a third charged or ionizable
3 moiety.

TELETYPE

1 25. The composition of claim 24 further comprising a plurality of
2 macromolecules, each of the macromolecules including a fourth charged or ionizable moiety,
3 wherein the plurality of macromolecules are associated with the inorganic particle via
4 electrostatic interaction with the plurality of inorganic particle linking groups.

1 26. The composition of claim 21, wherein the inorganic particle comprises Ag,
2 Au, or a phosphor.

1 27. The composition of claim 21, wherein the first charged or ionizable group
2 includes an hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or
3 quaternary ammonium.

1 28. The composition of claim 21, wherein the second charged or ionizable group
2 includes an hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or
3 quaternary ammonium.

1 29. The composition of claim 21, wherein the linking group has the formula:

$$(R_1)_a-R_2-[(R_3)_b(R_4)_c]_d$$

3 wherein

4 R_1 is selected from the group consisting of C1-C100 heteroalkyl, C2-C100
5 heteroalkenyl, heteroalkynyl, -OR, -SH, -NHR, -NR'R'', -N(O)HR, -N(O)R'R'', -PHR,
6 -PR'R'', -P(NR'R'')NR'R'', -P(O)R'R'', -P(O)(NR'R'')NR'R'', -P(O)(OR')OR'', -P(O)OR,
7 -P(O)NR'R'', -P(S)(OR')OR'', and -P(S)OR, wherein R, R', R'' are independently selected
8 from the group consisting of H, a branched or unbranched C1-C100 alkyl, a branched or
9 unbranched C2-C100 alkenyl, a branched or unbranched C2-C100 alkynyl, a branched or
10 unbranched C1-C100 heteroalkyl, a branched or unbranched C2-C100 heteroalkenyl, a
11 branched or unbranched C2-C100 heteroalkynyl, with the proviso that when a is greater than
12 1 the R_1 groups can be attached to the R_2 or R_3 groups at the same or different atoms within
13 those groups, the R_1 groups can be the same or different, or the R_1 groups can form a six,
14 seven, eight, nine, or ten membered cycloalkyl, cycloalkenyl, thereocyclic, aryl, heteroaryl,
15 or a six- to thirty-membered crown ether or heterocrown ether;

16 R₂ is selected from a bond, a branched or unbranched C2-C100 alkylene, a branched
17 or unbranched C2-C100 alkenylene, a branched or unbranched C2-C100 heteroalkenylene,
18 cycloalkyl, cycloalkenyl, cycloalkynyl, heterocyclic, aryl, and heteroaryl;

19 R₃ is selected from a branched or unbranched C2-C100 alkylene, a branched or
20 unbranched C2-C100 alkenylene, a branched or unbranched C2-C100 heteroalkenylene,
21 cycloalkyl, cycloalkenyl, cycloalkynyl, heterocyclic, aryl, and heteroaryl;

22 R₄ is selected from the group consisting of hydrogen, a carboxylate, a
23 thiocarboxylate, an amide, a hydrazine, a sulfonate, a sulfoxide, a sulfone, a sulfite, a
24 phosphate, a phosphonate, a phosphonium ion, an alcohol, a thiol, an amine, an ammonium,
25 an alkyl ammonium, a nitrate; and

26 a is 1 to 40, b is 0 to 3, c is 1 to 30, d is 1 to 3, and when d is 2 or 3 the R₃ groups can
27 be the same or different or can be linked together to form a five to ten members cycloalkyl,
28 cycloalkenyl, heterocyclic, aryl, or heteroaryl.

1 30. The composition of claim 21, wherein the linking group has the formula
2 HS-C₂H₄-CH(SH)-(C₄H₈)-COOH.

1 31. The composition of claim 21, wherein the second charged or ionizable moiety
2 is a leucine zipper.

1 32. The composition of claim 21, wherein the second charged or ionizable moiety
2 is polyaspartate.

1 33. The composition of claim 21, wherein the fusion protein includes a maltose
2 binding protein.

1 34. The composition of claim 21, wherein the fusion protein includes an
2 immunoglobulin G binding protein.

1 35. A method of forming an ionic conjugate, comprising:

2 providing an inorganic particle including a linking group having a distal end and a
3 proximal end, the distal end being bound to an outer surface of the inorganic particle and the
4 proximal end including a first charged or ionizable moiety; and

5 contacting a macromolecule having a second charged or ionizable moiety with the
6 inorganic particle, wherein the first and second charged or ionizable moieties electrostatically
7 associate the inorganic particle with the macromolecule to form an ionic conjugate.

1 36. The method of claim 35, wherein the inorganic particle is a semiconducting
2 nanocrystal.

1 37. The method of claim 36, wherein the semiconductor nanocrystal includes a
2 first semiconductor material selected from the group consisting of a Group II-VI compound,
3 a Group II-V compound, a Group III-VI compound, a Group III-V compound, a Group IV-
4 VI compound, a Group I-III-VI compound, a Group II-IV-VI compound, and a Group II-IV-
5 V compound.

1 38. The method of claim 37, wherein the first semiconductor material is selected
2 from the group consisting of ZnS, ZnSe, ZnTe, CdS, CdSe, CdTe, HgS, HgSe, HgTe, AlN,
3 AlP, AlAs, AlSb, GaN, GaP, GaAs, GaSb, GaSe, InN, InP, InAs, InSb, TlN, TlP, TlAs, TlSb,
4 PbS, PbSe, PbTe, and mixtures thereof.

1 39. The method of claim 38, wherein the first semiconductor material is CdSe.

1 40. The method of claim 39, wherein the first semiconductor material is
2 overcoated with a second semiconductor material.

1 41. The method of claim 40, wherein the second semiconductor material is ZnS,
2 ZnO, ZnSe, ZnTe, CdS, CdO, CdSe, CdTe, MgS, MgSe, HgO, HgS, HgSe, HgTe, AlN, AlP,
3 AlAs, AlSb, GaN, GaP, GaAs, GaSb, GaSe, InN, InP, InAs, InSb, TlN, TlP, TlAs, TlSb, PbS,
4 PbSe, PbTe, SiO₂, or mixtures thereof.

1 42. The method of claim 35, wherein the inorganic particle further comprises a
2 plurality of linking groups each independently including a third charged or ionizable moiety.

1 43. The method of claim 35 further comprising a plurality of macromolecules,
2 each of the macromolecules including a fourth charged or ionizable moiety, wherein the
3 plurality of macromolecules are associated with the inorganic particle via electrostatic
4 interaction with the plurality of inorganic particle linking groups.

1 44. The method of claim 35, wherein the inorganic particle comprises Ag, Au, or
2 a phosphor.

1 45. The method of claim 35, wherein the first charged or ionizable group includes
2 a hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or quaternary
3 ammonium.

1 46. The method of claim 35, wherein the second charged or ionizable group
2 includes an hydroxide, alkoxide, carboxylate, sulfonate, phosphate, phosphonate, or
3 quaternary ammonium.

1 47. The method of claim 35, wherein the linking group has the formula:

$$(R_1)_a - R_2 - [(R_3)_b (R_4)_c]_d$$

3 wherein

4 R₁ is selected from the group consisting of C1-C100 heteroalkyl, C2-C100
5 heteroalkenyl, heteroalkynyl, -OR, -SH, -NHR, -NR'R'', -N(O)HR, -N(O)R'R'', -PHR,
6 -PR'R'', -P(NR'R'')NR'R'', P(O)R'R'', P(O)(NR'R'')NR'R'', -P(O)(OR')OR'', P(O)OR,
7 P(O)NR'R'', -P(S)(OR')OR'', and P(S)OR, wherein R, R', R'' are independently selected from
8 the group consisting of H, a branched or unbranched C1-C100 alkyl, a branched or
9 unbranched C2-C100 alkenyl, a branched or unbranched C2-C100 alkynyl, a branched or
10 unbranched C1-C100 heteroalkyl, a branched or unbranched C2-C100 heteroalkenyl, a
11 branched or unbranched C2-C100 heteroalkynyl, with the proviso that when a is greater than
12 1 the R₁ groups can be attached to the R₂ or R₃ groups at the same or different atoms within

13 those groups, the R₁ groups can be the same or different, or the R₁ groups can form a six,
14 seven, eight, nine, or ten membered cycloalkyl, cycloalkenyl, thereocyclic, aryl, heteroaryl,
15 or a six- to thirty-membered crown ether or heterocrown ether;

16 R₂ is selected from a bond (i.e., R₂ is absent in which case R₁ attaches to R₃), a
17 branched or unbranched C2-C100 alkylene, a branched or unbranched C2-C100 alkenylene,
18 a branched or unbranched C2-C100 heteroalkenylene, cycloalkyl, cycloalkenyl,
19 cycloalkynyl, heterocyclic, aryl, and heteroaryl;

20 R₃ is selected from a branched or unbranched C2-C100 alkylene, a branched or
21 unbranched C2-C100 alkenylene, a branched or unbranched C2-C100 heteroalkenylene,
22 cycloalkyl, cycloalkenyl, cycloalkynyl, heterocyclic, aryl, and heteroaryl;

23 R₄ is selected from the group consisting of hydrogen, a carboxylate, a
24 thiocarboxylate, and amid, an amine, a hydrazine, a sulfonate, a sulfoxide, a sulfone, a
25 sulfite, a phosphate, a phosphonate, a phosphonium ion, an alcohol, a thiol, an amine, an
26 ammonium, an alkyl ammonium, a nitrate; and

27 a is 1 to 4, b is 0 to 3, c is 1 to 3, d is 1 to 3, and when d is 2 or 3 the R₃ groups can be
28 the same or different or can be linked together to form a five to ten members cycloalkyl,
29 cycloalkenyl, heterocyclic, aryl, or heteroaryl.

1 48. The method of claim 35, wherein the linking group has the formula
2 HS-C₂H₄-CH(SH)-(C₄H₈)-COOH.

1 49. The method of claim 35, wherein the macromolecule includes a polypeptide
2 or a polynucleotide.

1 50. The method of claim 49, wherein the macromolecule includes a polypeptide.

1 51. The method of claim 50, wherein the second charged or ionizable moiety is a
2 leucine zipper.

1 52. The method of claim 50, wherein the second charged or ionizable moiety is
2 polyaspartate.

1 53. The method of claim 50, wherein the polypeptide includes a maltose binding
2 protein.

1 54. The method of claim 50, wherein the polypeptide includes an immunoglobulin
2 G binding protein.

1 55. The method of claim 35 further including forming the macromolecule by
2 recombinant methods.

1 56. The method of claim 35 further including forming the macromolecule by
2 synthetic methods.

1 57. A method of detecting the presence of a predetermined species in a solution,
2 comprising:

3 contacting a solution with an ionic conjugate, wherein the ionic conjugate includes an
4 inorganic particle electrostatically associated with a macromolecule, the macromolecule
5 capable of binding specifically to the predetermined species.

1 58. The method of claim 57 further comprising forming an ionic conjugate by
2 adding an inorganic particle and a macromolecule to the solution, wherein the inorganic
3 particle includes a linking group having a distal end and a proximal end, the distal end being
4 bound to an outer surface of the inorganic particle and the proximal end including a first
5 charged or ionizable moiety and the macromolecule includes a second charged or ionizable
6 moiety, the first and second charged or ionizable moieties associating electrostatically to
7 form the ionic conjugate.